

# SiPM Calibration Report

## 1 Peak Analysis

### 1.1 Measurements

Setup description.

For each set, we read 2 exits,  $X1$  and  $X5$ , where the latter is an amplification of  $\sim 5$  times the first one. For each set, we measure the breakdown voltage  $U_{breakdown}$  at various temperatures. They are listed in Table 1. The error on the temperature is  $0.2^\circ\text{C}$ , the error on the measured breakdown voltage is  $5\text{ mV}$ . The laser light is  $380\text{ nm}$ .

#### 1.1.1 First set - FBK 1x1

We consider two temperatures ( $T=0^\circ\text{C}$  and  $T = 25^\circ\text{C}$ ) and five high voltage ( $U_{HV}$ ) settings ( $26\text{ V}$ ,  $27\text{ V}$ ,  $28\text{ V}$ ,  $29\text{ V}$ , and  $30\text{ V}$ ), for a total of 8 different configurations. LED is set at  $7.5$ .

#### 1.1.2 Second set - FBK 3x3

We consider two temperatures ( $T=0^\circ\text{C}$  and  $T = 25^\circ\text{C}$ ) and four  $U_{HV}$  settings ( $27\text{ V}$ ,  $27.5\text{ V}$ , and  $28\text{ V}$ ) for a total of 6 different configurations. LED is set at  $7.0$ .

#### 1.1.3 Third set - Hamamatsu 50u

We consider two temperatures ( $T=0^\circ\text{C}$  and  $T = 25^\circ\text{C}$ ) and four  $U_{HV}$  settings ( $70\text{ V}$ ,  $70.5\text{ V}$ ,  $71\text{ V}$ , and  $71.5\text{ V}$ ), for a total of 5 different configurations. LED is set at  $7.3$ .

T ( $^\circ\text{C}$ )	U <sub>breakdown</sub> (V)		
	FBK 1x1	FBK 3x3	HAM 50u
0	25.12	24.64	68.9
10	25.34	24.87	69.4
25	25.67	25.27	70.2

Table 1: Values of the breakdown voltage for each temperature configuration.

## 1.2 Analysis Method

The developed peak fitting procedures were computed adopting the IDL software, in particular the *mpfitfun* fit packages. Depending on the specific spectrum, 7 or more Gaussians in the form

$$G(x) = \frac{A}{w} \cdot \sqrt{\frac{4 \ln 2}{\pi}} e^{-4 \ln 2 \frac{(x - x_c)^2}{w^2}} \quad (1)$$

were added in order to fit the data. The maximum number of considered Gaussians is 17. The three free parameters are

- the peak area **A**;
- the peak center **x<sub>c</sub>**; and
- the full width at half maximum **w**

*w* is related to the standard deviation ( $\sigma$ ) of the distribution through the relation

$$w = 2 \sqrt{2 \ln 2} \cdot \sigma \approx 2.35 \cdot \sigma. \quad (2)$$

No background contribution function is added to the multi-gaussian fit. Spectra were always rebinned (X1: binning = 0.0008; X5: binning=0.004). More discussion about binning spectra required!

At higher ADC values (>1200), the detectors are not always able to fully separate two peaks lying close to each other. This results in broadened peaks and in particular broadened tails of the peak distribution. Therefore, the fitting routines have difficulties in converging in finding the real peaks' areas, positions and widths. In order to improve the fitting quality, particular constraints on peak parameters of single peak components were set before running the fitting routines. Parameters were either limited between some upper and lower boundaries or even fixed to a certain value.

### 1.2.1 Systematic Errors

TBD.

## 1.3 Results

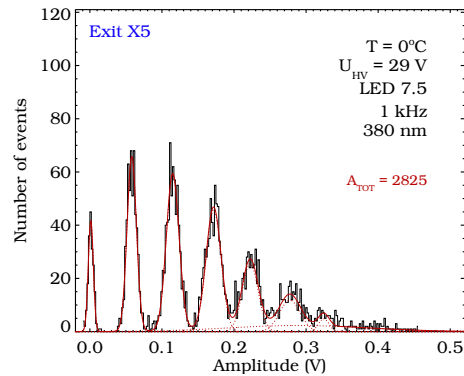
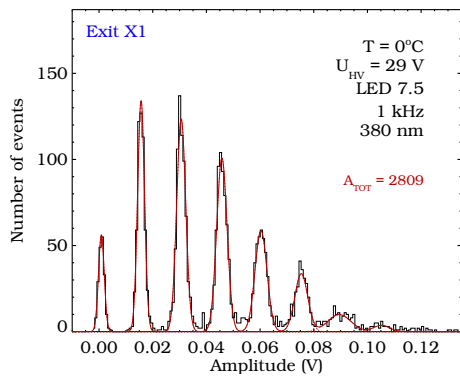
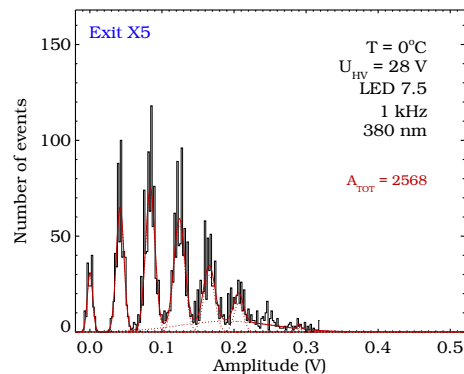
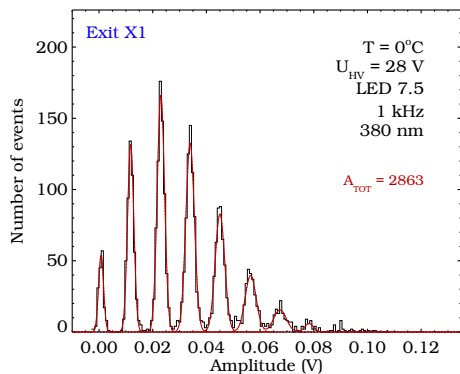
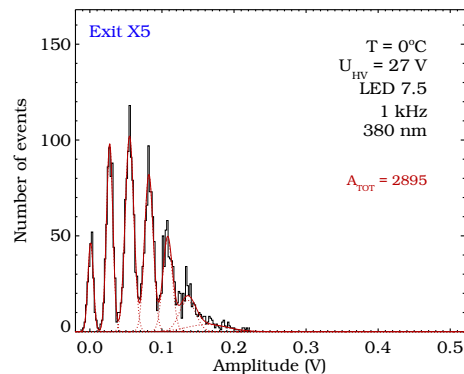
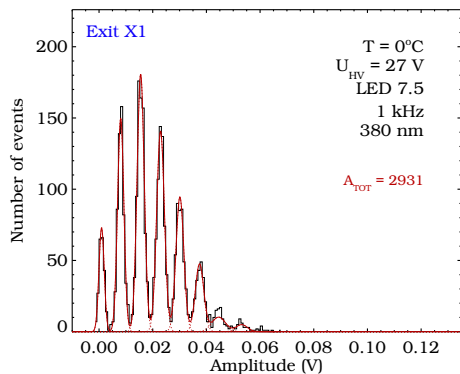
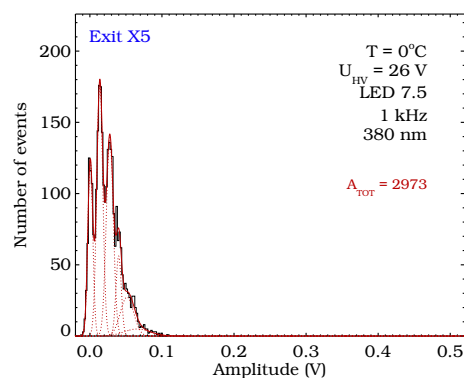
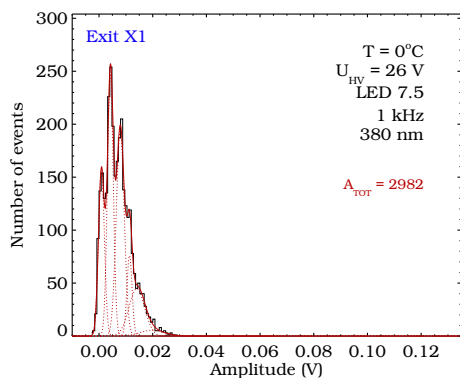
Results for each considered configuration are shown in the next pages. Fits to the data are shown in *red*. Gaussian components, describing the photoelectron peaks, are shown as *dotted red curves*. The total fitted area (sum of all Gaussian areas *A*) is always reported in the top right corner as  $A_{ev}$ , together with other info for each configuration. These are also shown in the first 3 columns of Table 2.

# FBK 1x1 - Amplitudes

LED 7.5; T = 0°

X1

X5

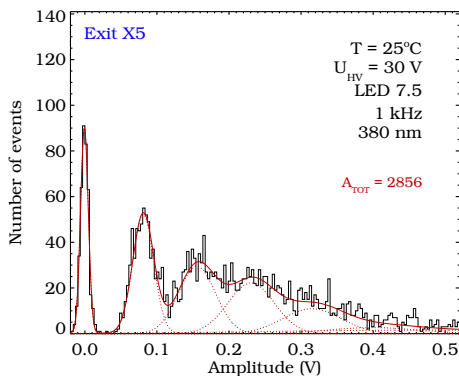
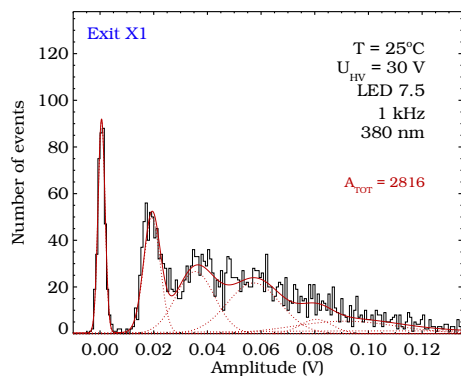
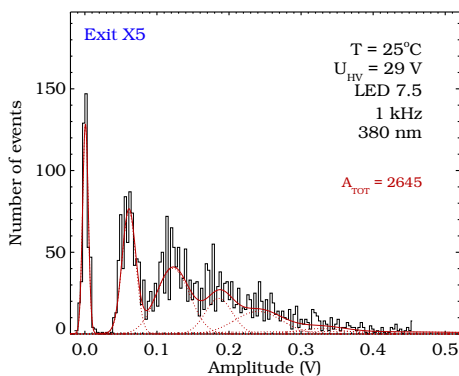
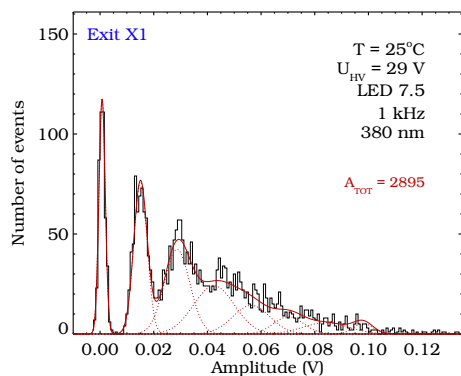
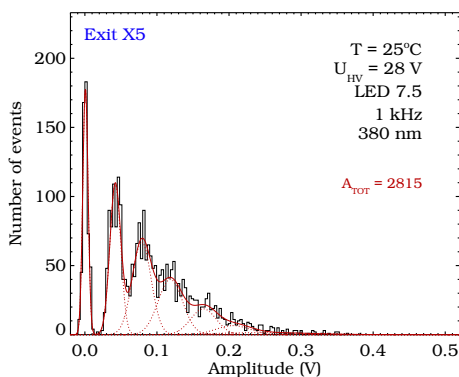
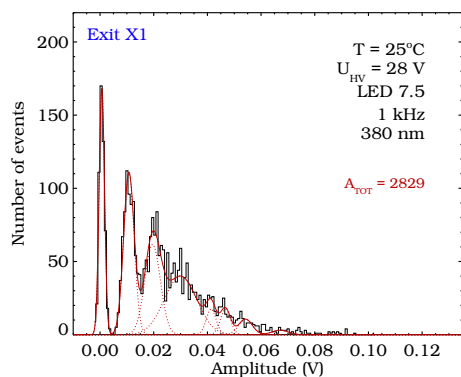
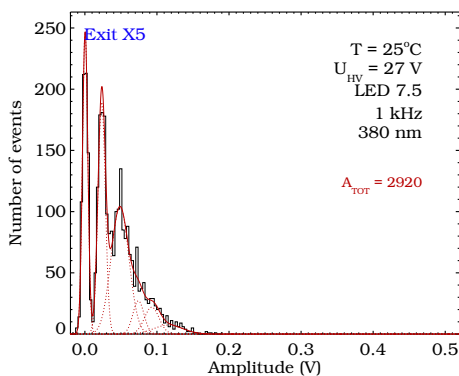
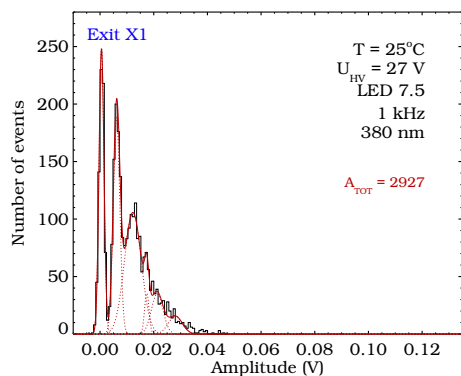


# FBK 1x1 - Amplitudes

LED 7.5; T = 25°

X1

X5

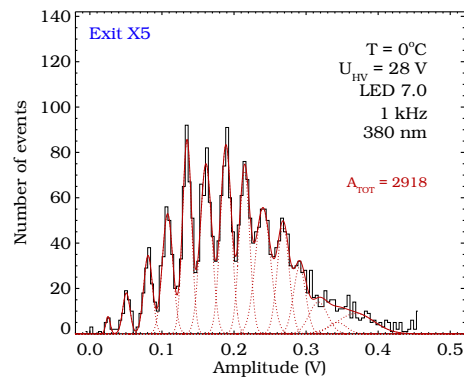
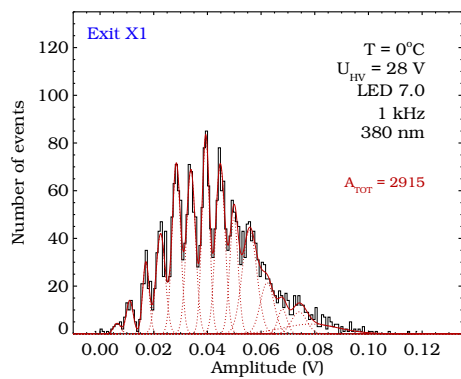
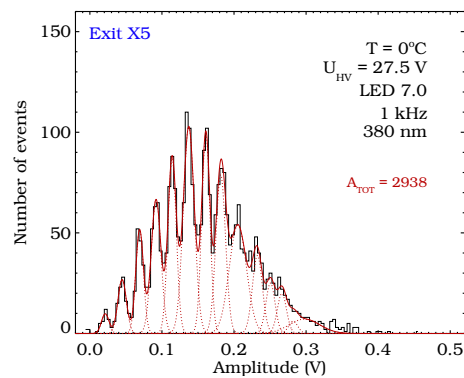
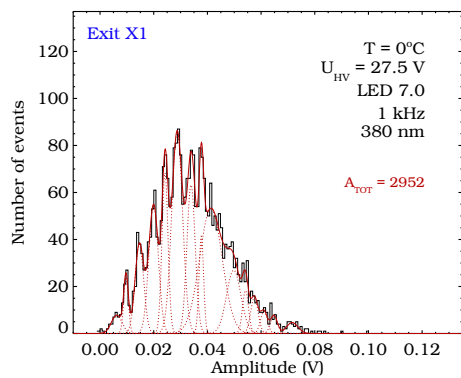
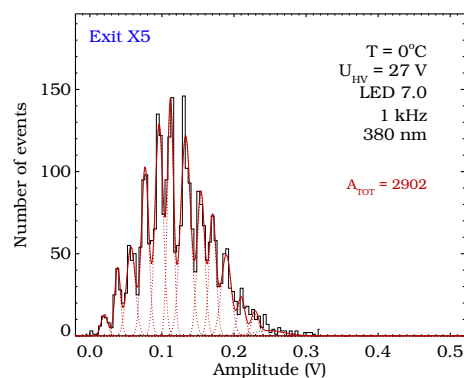
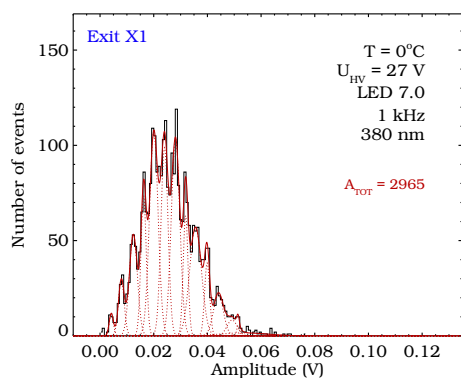


# FBK 3x3 - Amplitudes

LED 7.0; T = 0°

X1

X5

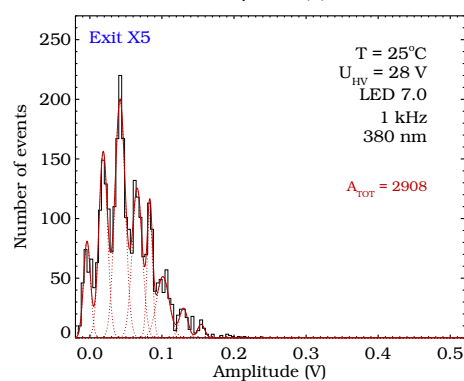
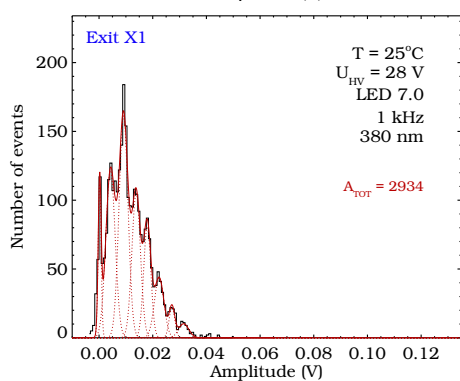
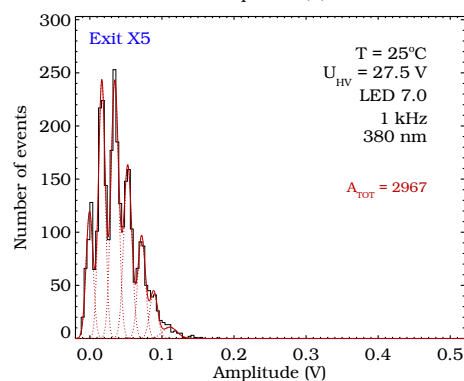
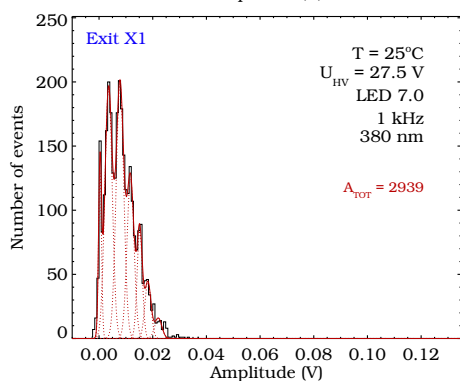
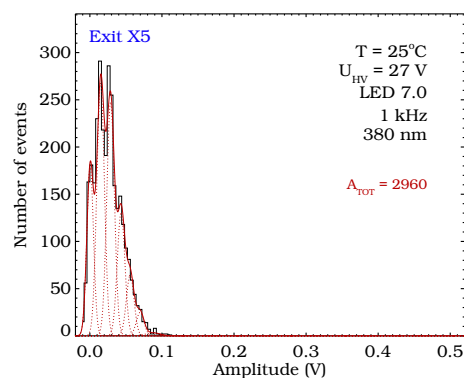
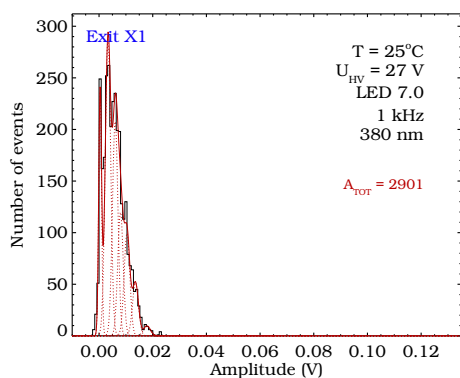


# FBK 3x3 - Amplitudes

LED 7.0; T = 25°

X1

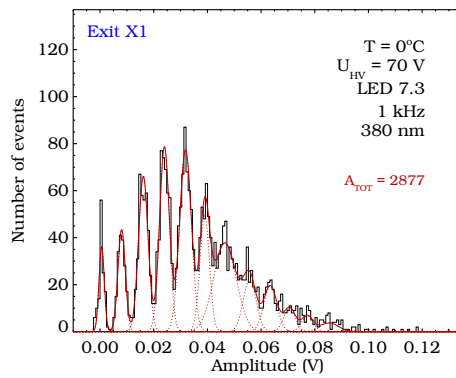
X5



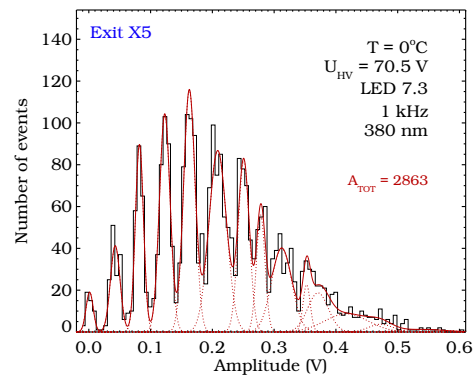
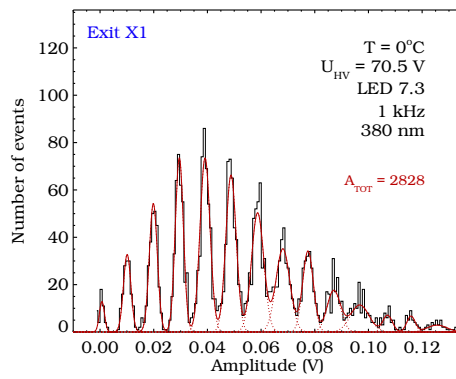
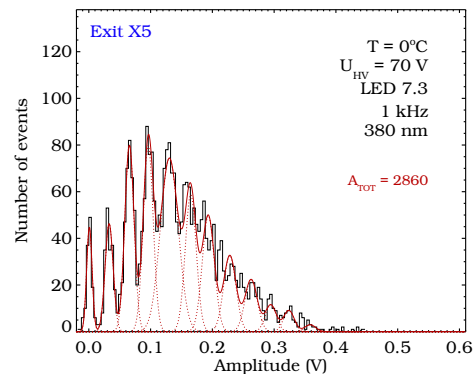
# Hamamatsu 50u - Amplitudes

LED 7.3; T = 0°

X1



X5

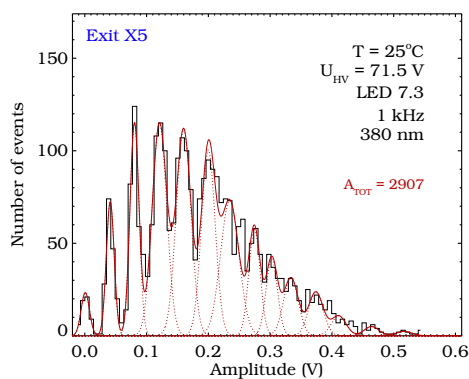
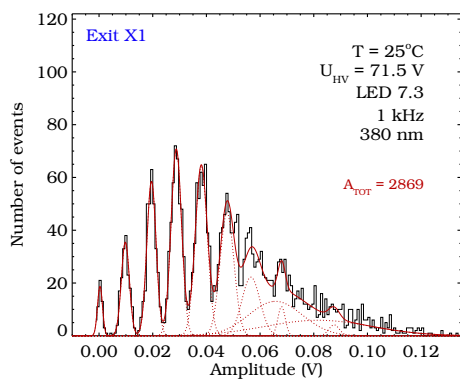
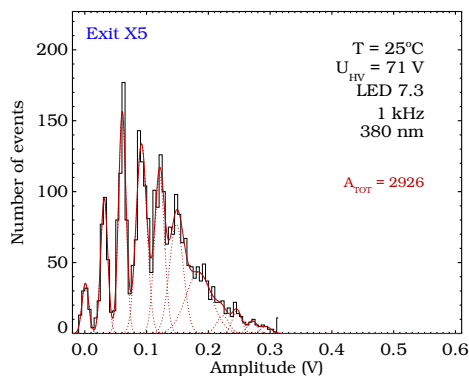
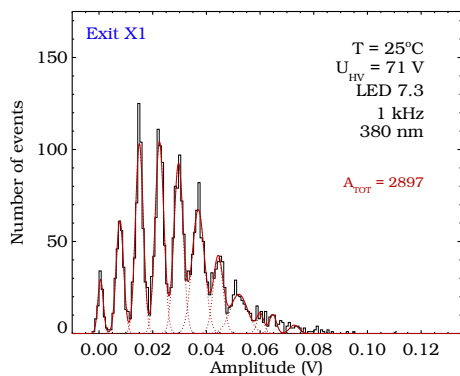
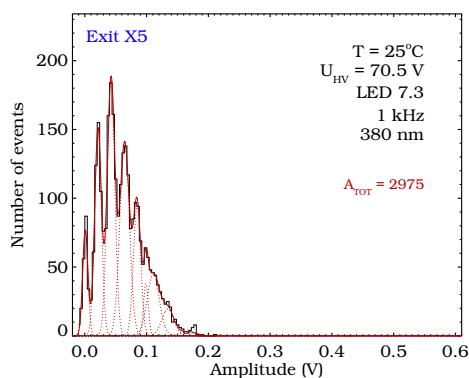
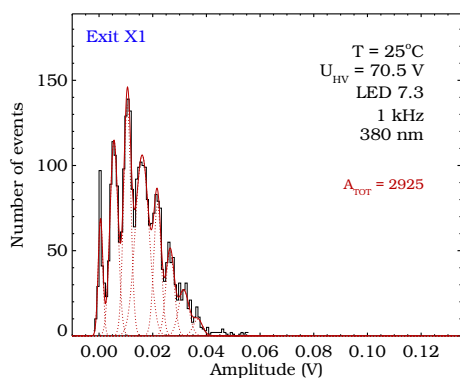


# Hamamatsu 50u - Amplitudes

LED 7.3; T = 25°

X1

X5

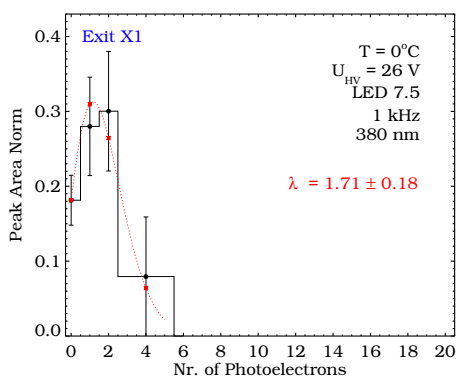




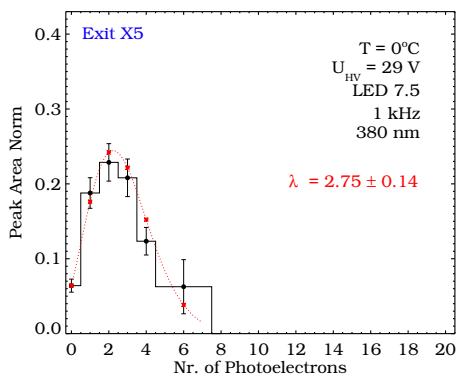
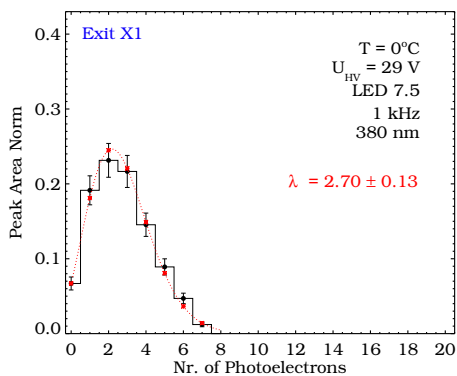
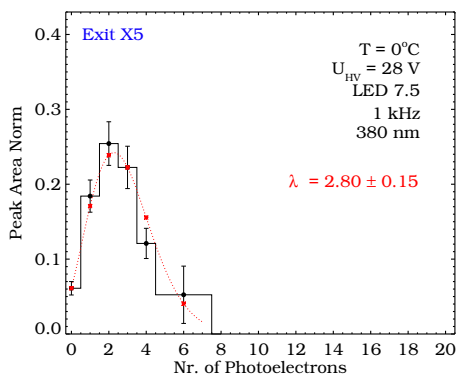
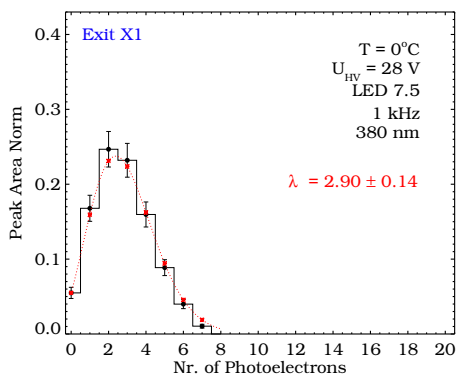
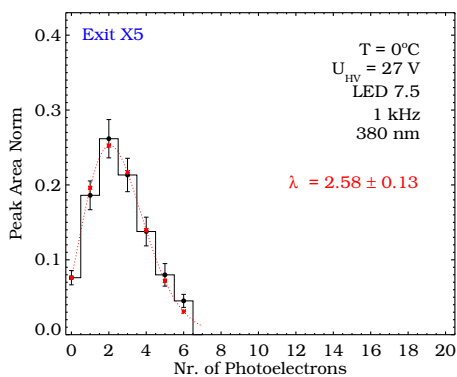
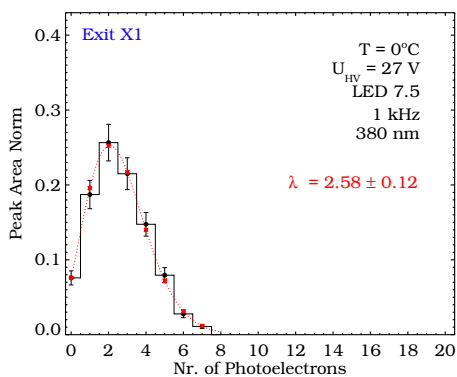
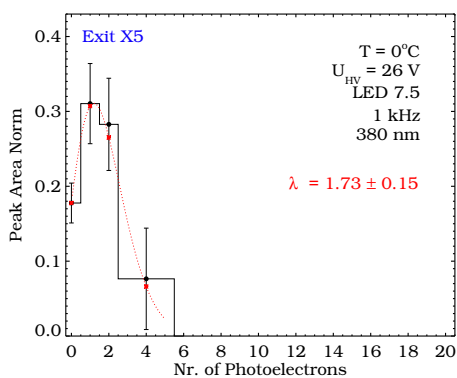
# FBK 1x1 - Poisson Distributions

LED 7.5; T = 0°

X1



X5

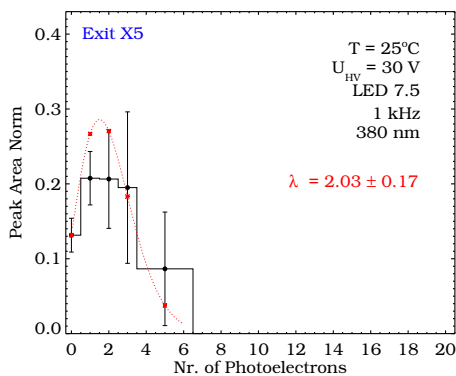
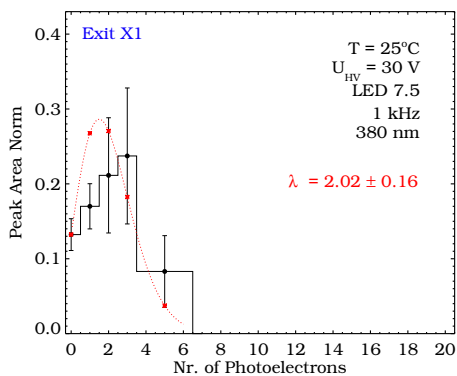
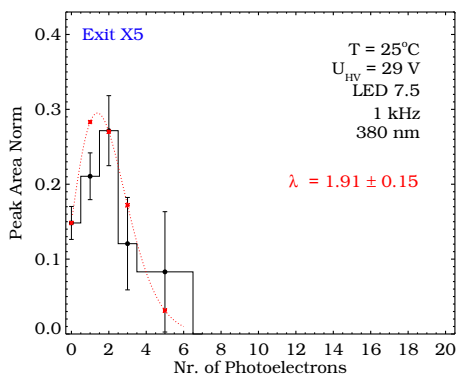
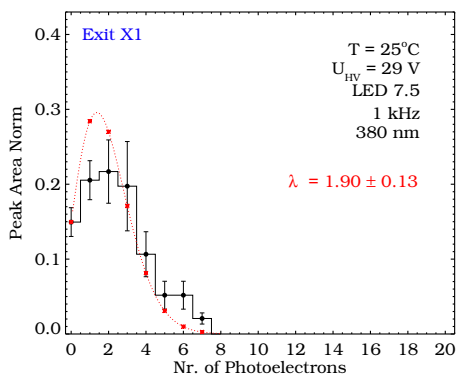
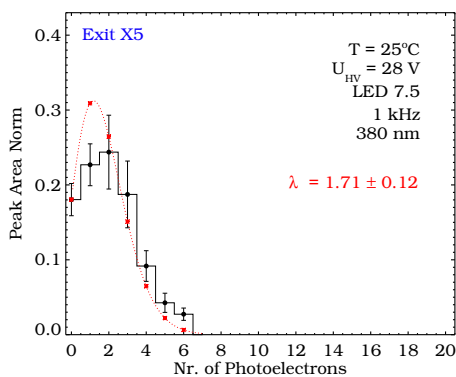
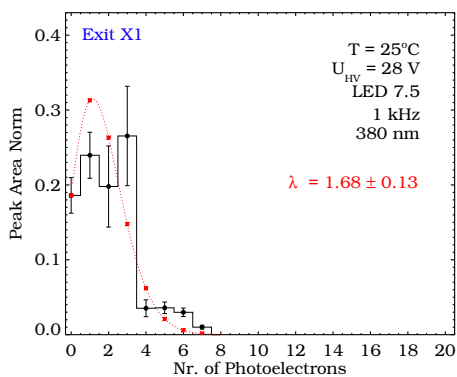
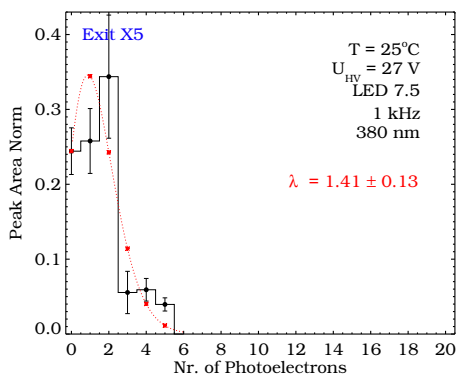
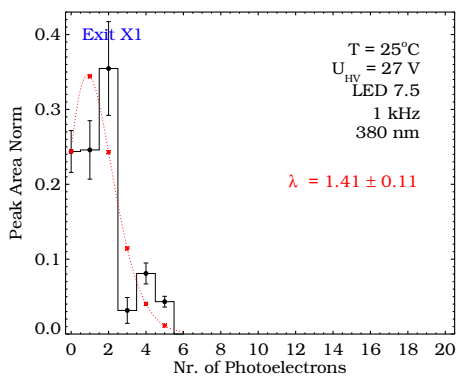


# FBK 1x1 - Poisson Distributions

LED 7.5; T = 25°

X1

X5

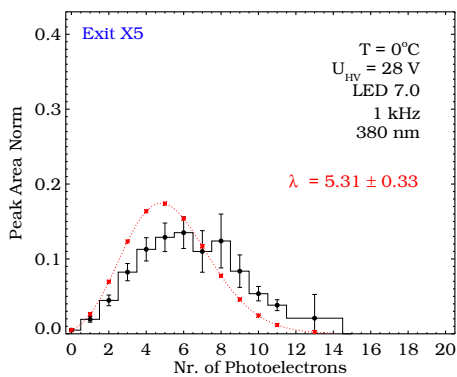
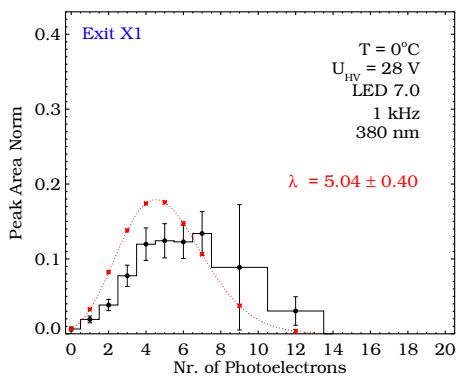
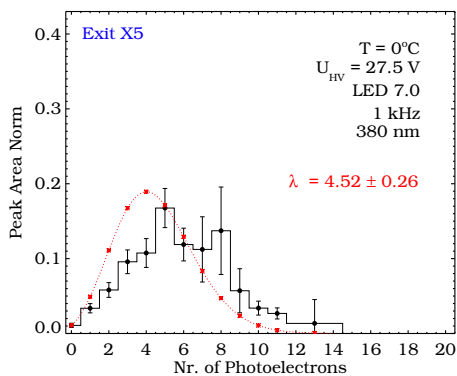
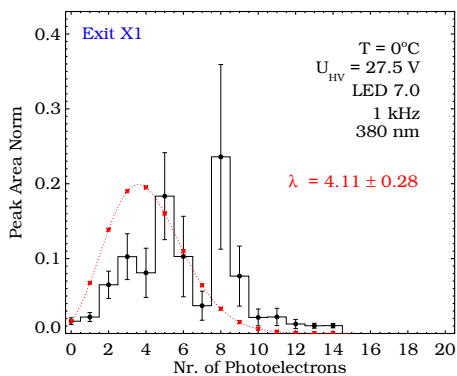
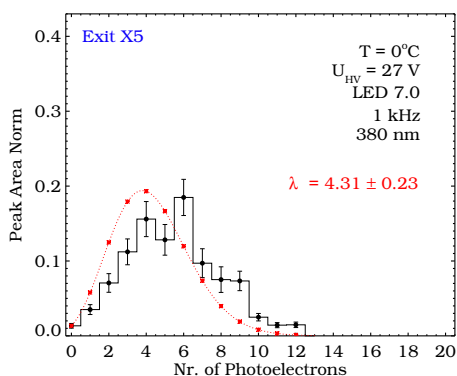
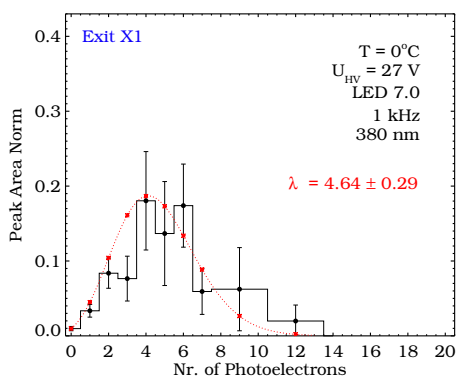


# FBK 3x3 - Poisson Distributions

LED 7.0; T = 0°

X1

X5

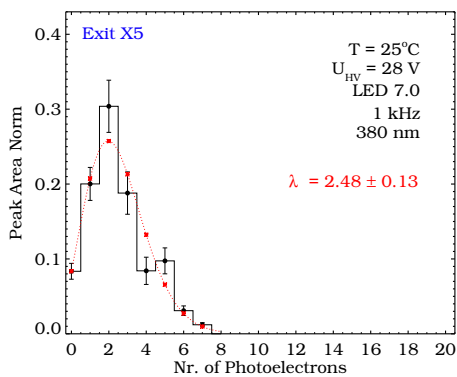
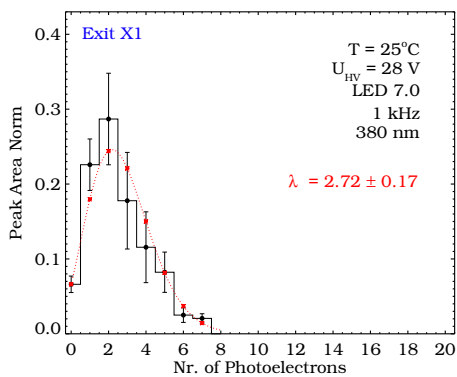
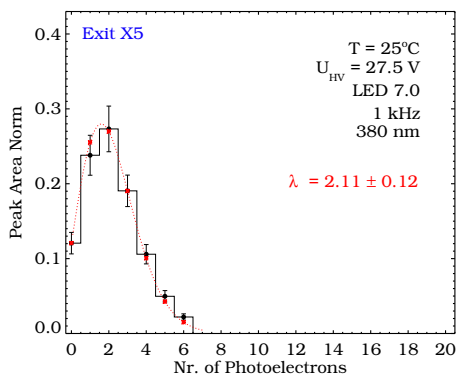
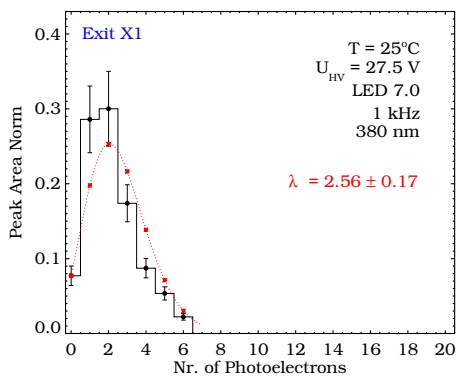
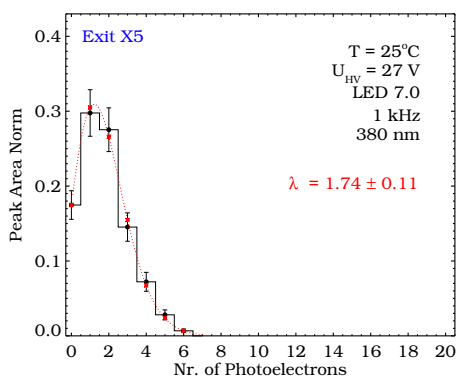
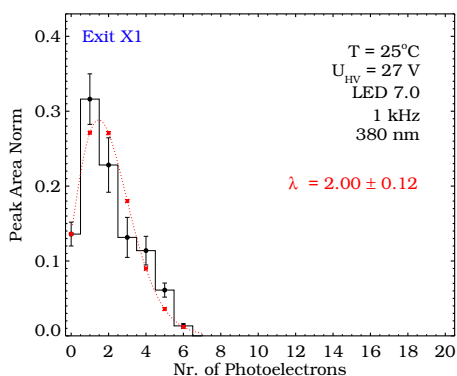


# FBK 3x3 - Poisson Distributions

LED 7.0; T = 25°

X1

X5

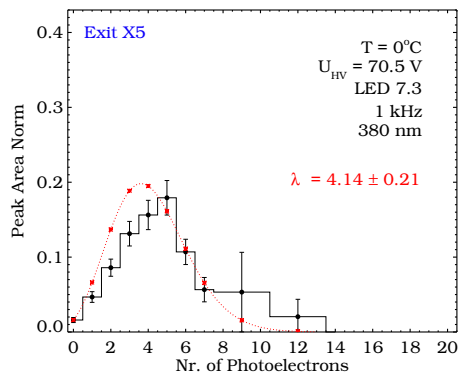
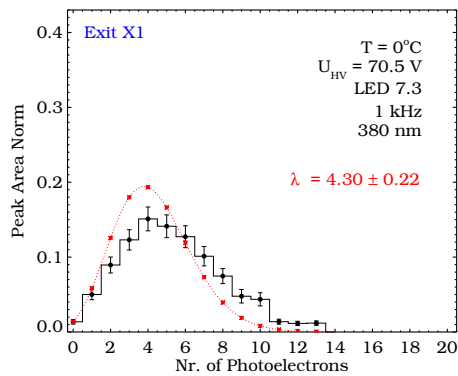
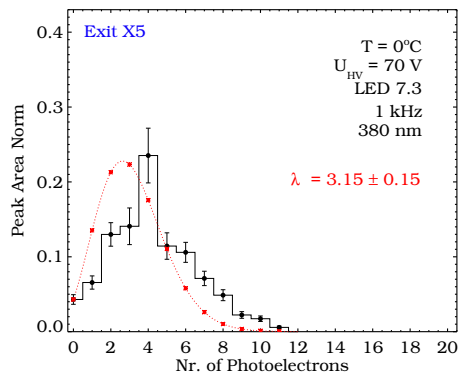
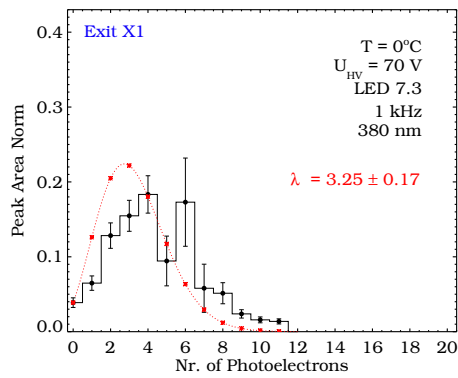


# Hamamatsu 50u - Poisson Distributions

LED 7.5; T = 0°

X1

X5

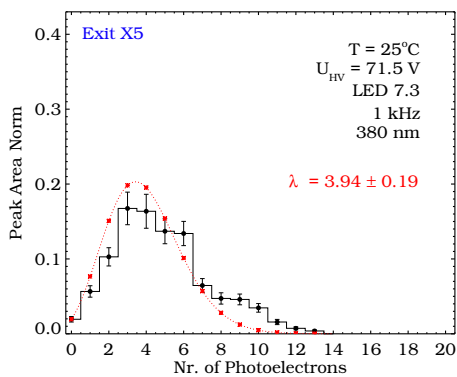
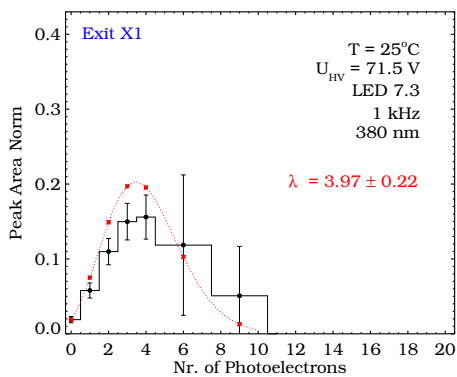
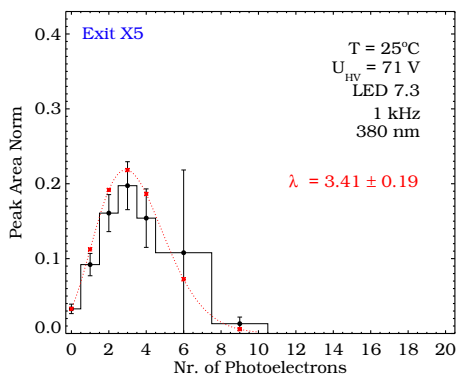
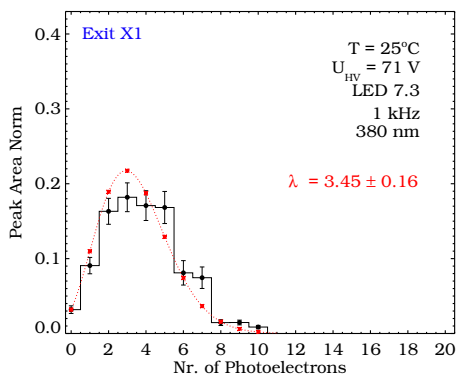
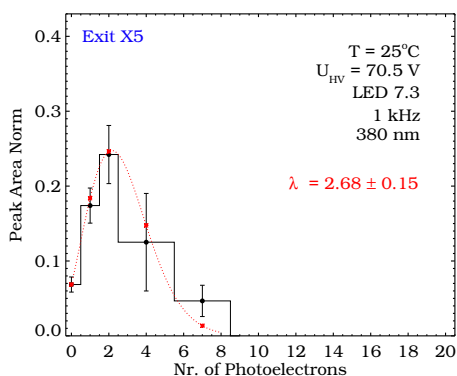
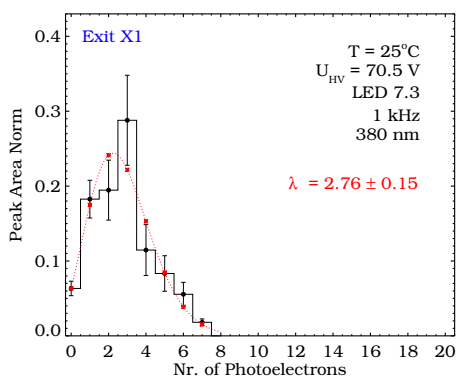


# Hamamatsu 50u - Poisson Distributions

LED 7.5; T = 25°

X1

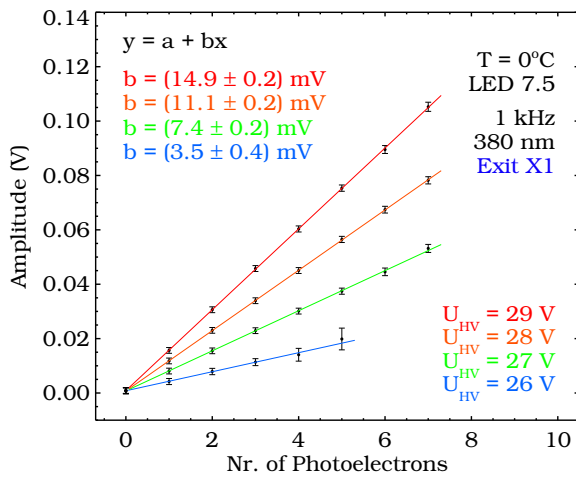
X5



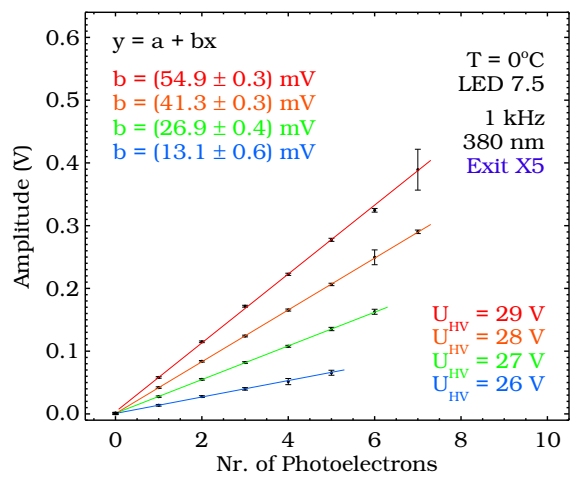
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T = 0 C

X1

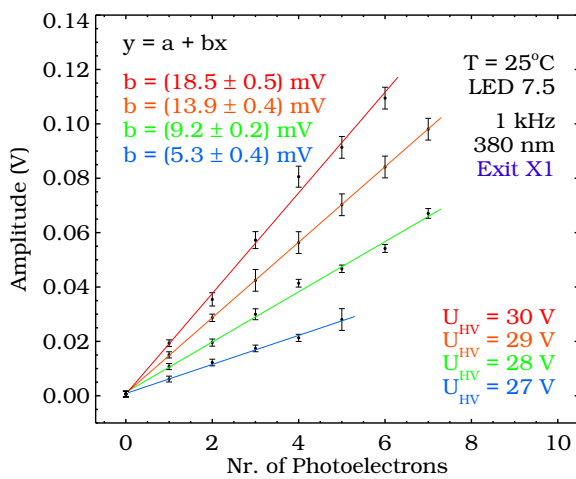


X5

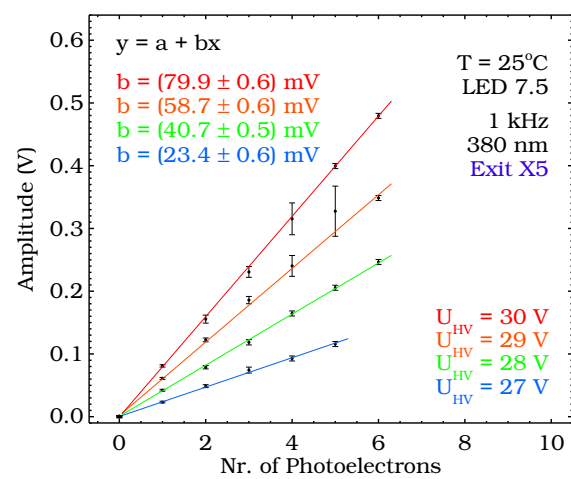


T = 25 C

X1



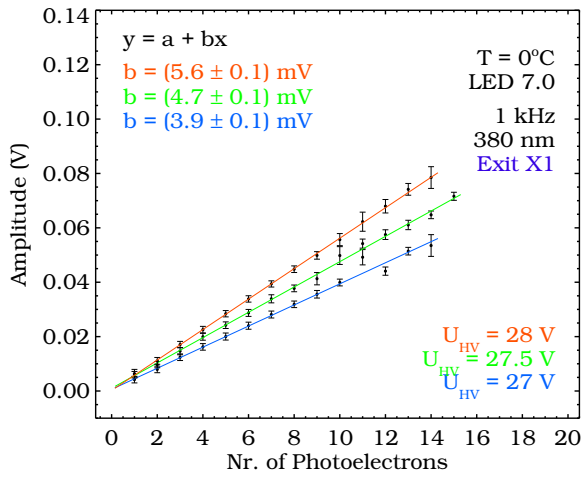
X5



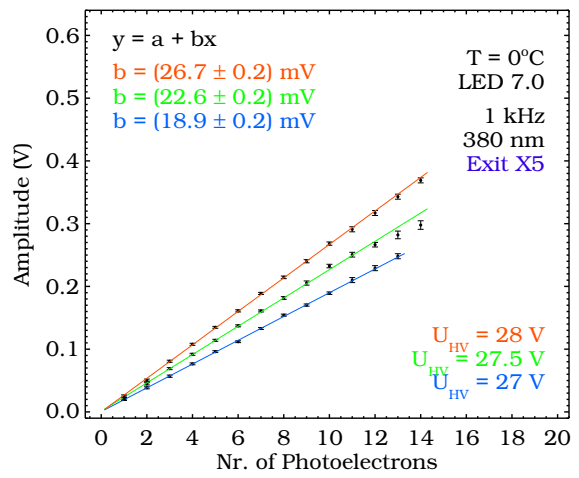
# FBK 3x3 - Gains

**T = 0 C**

**X1**

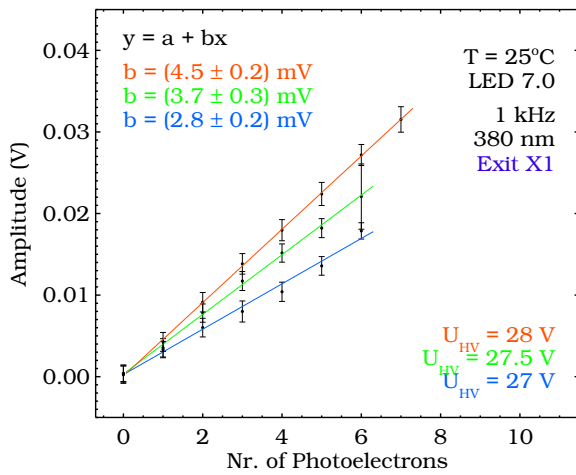


**X5**

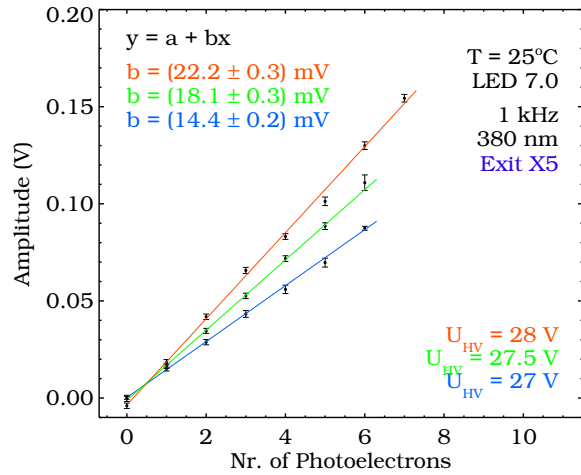


**T = 25 C**

**X1**



**X5**

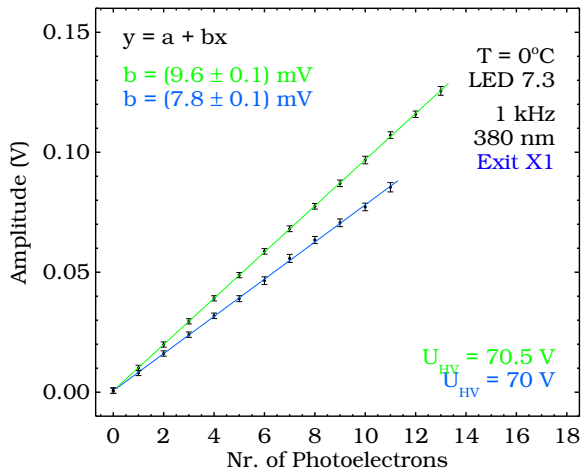




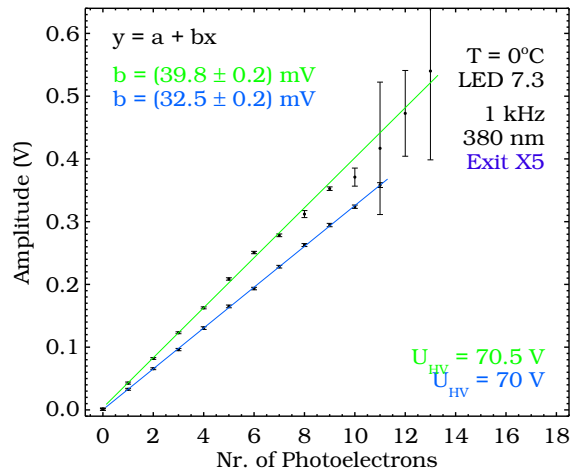
# Hamamatsu 50u - Gains

**T = 0 C**

**X1**

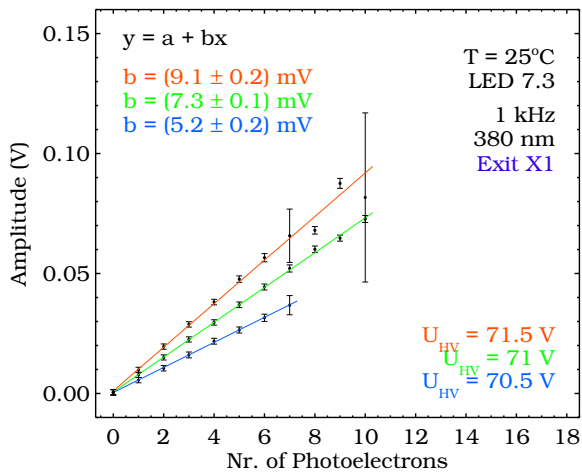


**X5**

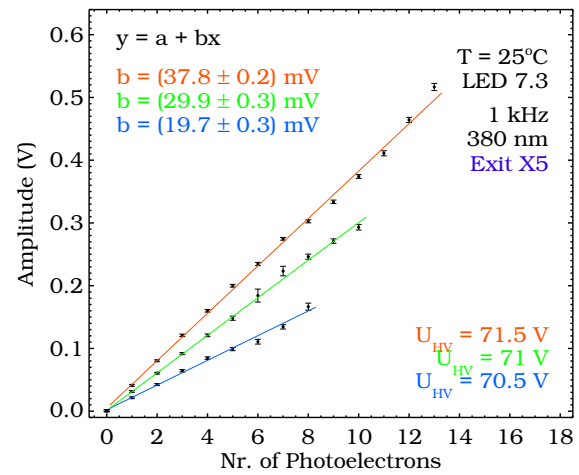


**T = 25 C**

**X1**



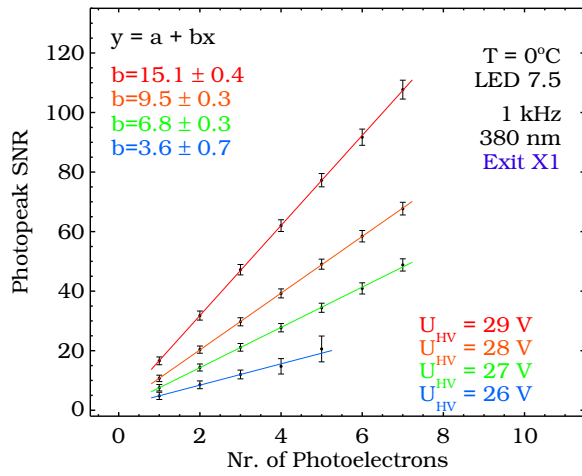
**X5**



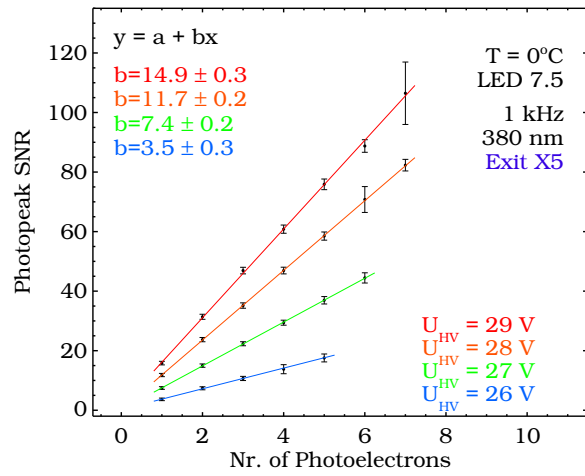
# FBK 1x1 - SNR

T = 0 C

X1

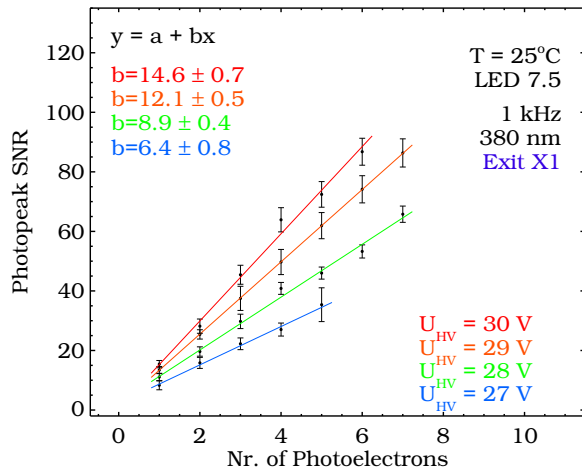


X5

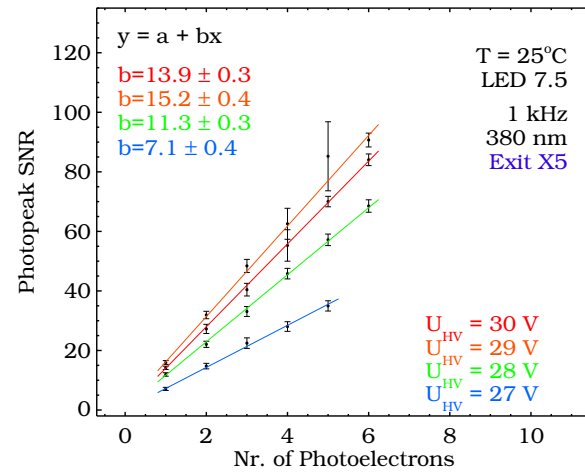


T = 25 C

X1



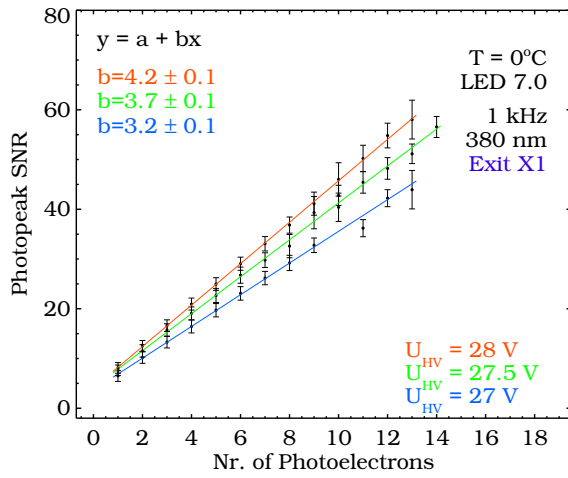
X5



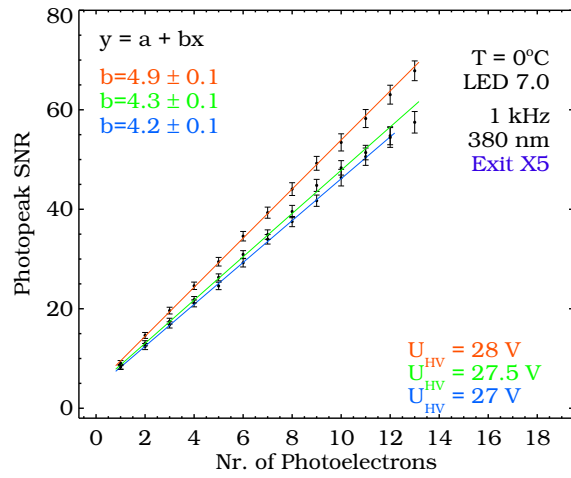
# FBK 3x3 - SNR

**T = 0 C**

**X1**

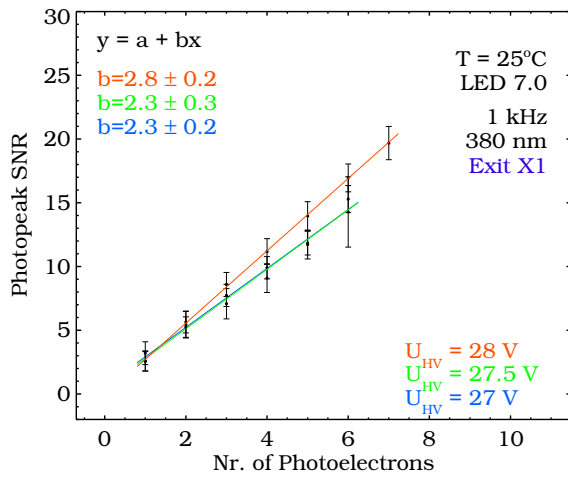


**X5**

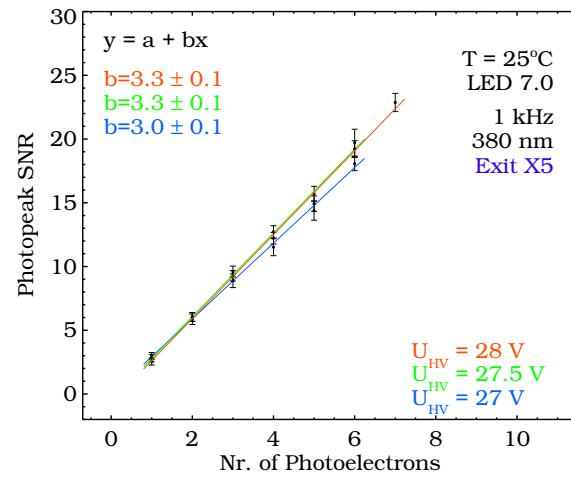


**T = 25 C**

**X1**

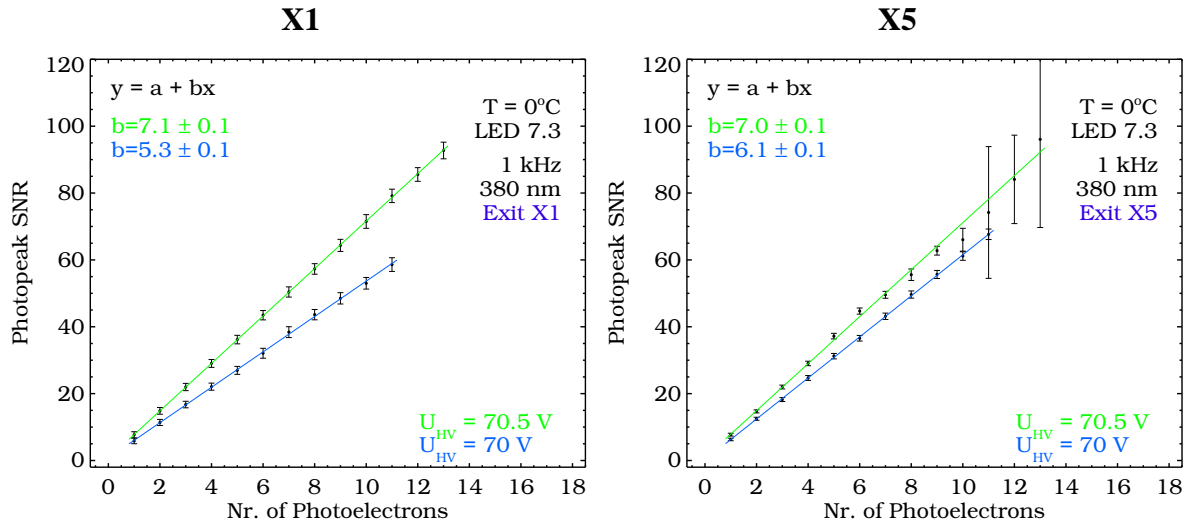


**X5**

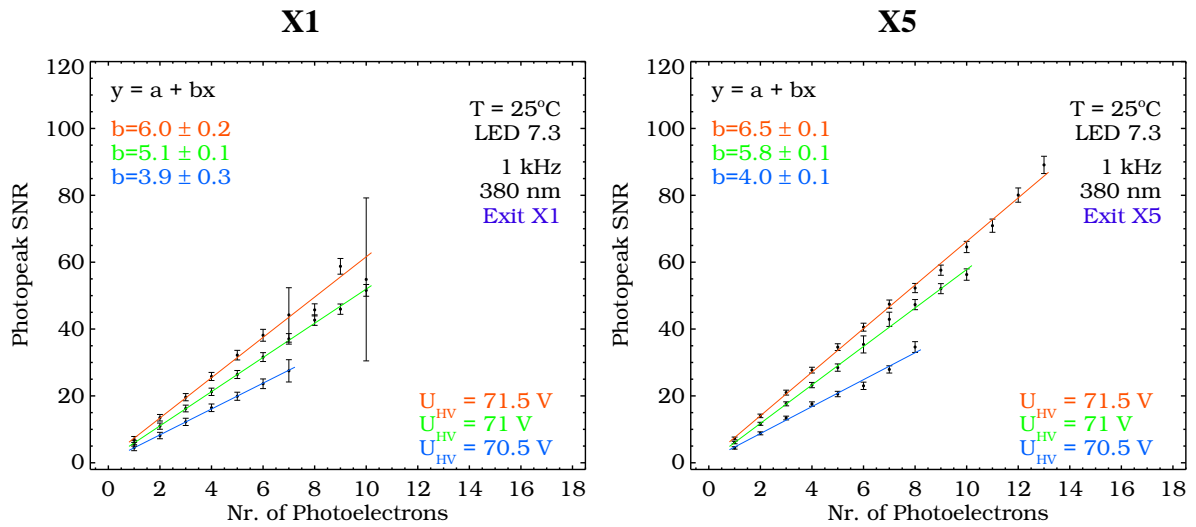


# Hamamatsu 50u - SNR

## T = 0 C

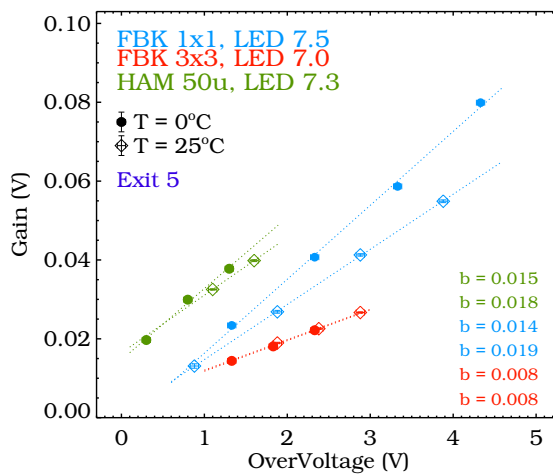
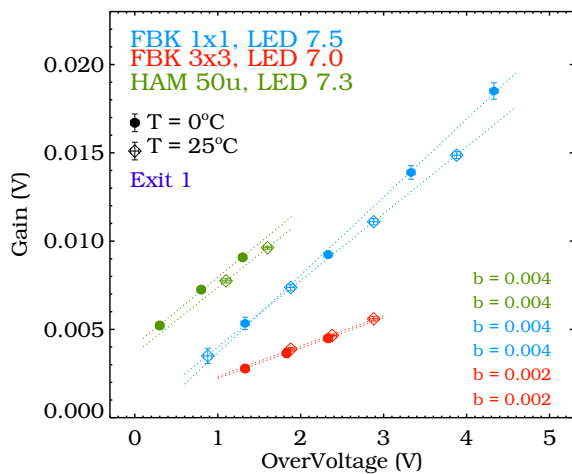


## T = 25 C

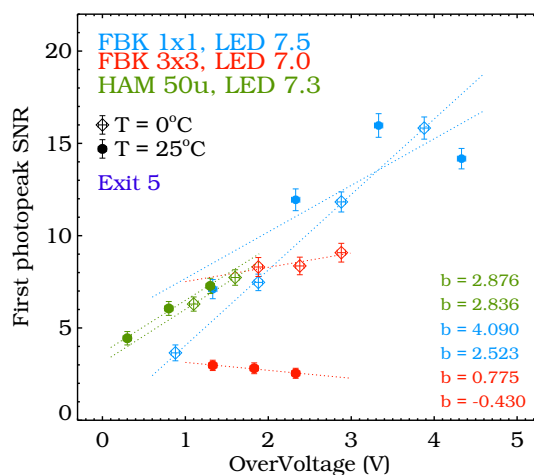
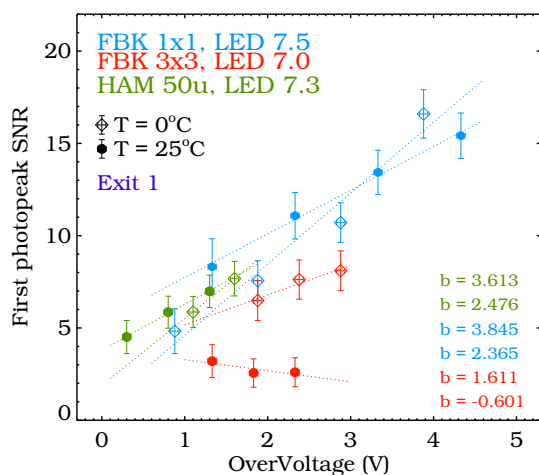


# Comparisons

## Gains vs OverVoltage



## First Peak SNR vs OverVoltage



## Gains vs First Peak SNR

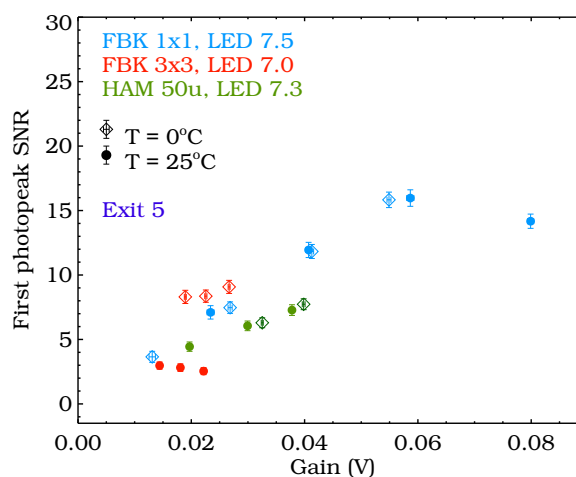
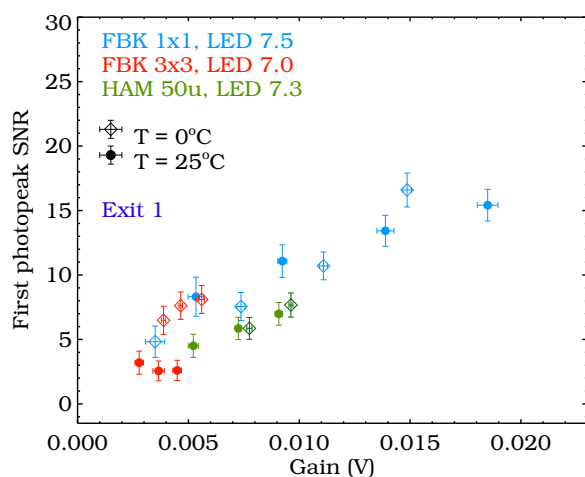


Table 2: Peak fitting results for all temperatures and HV configurations.

Set	T (°C)	U <sub>HV</sub> (V)	U <sub>OV</sub> (V)	LED	kHz	nm	$\lambda$	gain	SNR 1	
FBK 1x1 - X1	0	26	0.88	7.5	1.0	380	1.71 ± 0.18	0.0035 ± 0.0004	4.83 ± 1.21	
	0	27	1.88	7.5	1.0	380	2.58 ± 0.12	0.0074 ± 0.0002	7.56 ± 1.09	
	0	28	2.88	7.5	1.0	380	2.90 ± 0.14	0.0111 ± 0.0002	10.71 ± 1.08	
	0	29	3.88	7.5	1.0	380	2.70 ± 0.13	0.0149 ± 0.0002	16.59 ± 1.31	
	25	27	1.33	7.5	1.0	380	1.41 ± 0.11	0.0053 ± 0.0004	8.32 ± 1.52	
	25	28	2.33	7.5	1.0	380	1.68 ± 0.13	0.0092 ± 0.0002	11.08 ± 1.26	
	25	29	3.33	7.5	1.0	380	1.90 ± 0.13	0.0139 ± 0.0004	13.43 ± 1.20	
	25	30	4.33	7.5	1.0	380	2.02 ± 0.16	0.0185 ± 0.0005	15.42 ± 1.23	
FBK 3x3 - X1	0	27	1.88	7.0	1.0	380	4.64 ± 0.29	0.0039 ± 0.0001	6.49 ± 1.09	
	0	27.5	2.38	7.0	1.0	380	4.11 ± 0.28	0.0047 ± 0.0001	7.62 ± 1.06	
	0	28	2.88	7.0	1.0	380	5.04 ± 0.40	0.0056 ± 0.0001	8.10 ± 1.08	
	25	27	1.33	7.0	1.0	380	2.00 ± 0.12	0.0028 ± 0.0002	3.20 ± 0.89	
	25	27.5	1.83	7.0	1.0	380	2.56 ± 0.17	0.0037 ± 0.0003	2.56 ± 0.77	
HAM 50u - X1	25	28	2.33	7.0	1.0	380	2.72 ± 0.17	0.0045 ± 0.0002	2.60 ± 0.79	
	0	70	1.10	7.5	1.0	380	3.25 ± 0.17	0.0078 ± 0.0001	5.86 ± 0.84	
	0	70.5	1.60	7.5	1.0	380	4.30 ± 0.22	0.0096 ± 0.0001	7.67 ± 0.94	
	25	70.5	0.30	7.5	1.0	380	2.76 ± 0.15	0.0052 ± 0.0002	4.51 ± 0.89	
	25	71	0.80	7.5	1.0	380	3.45 ± 0.16	0.0073 ± 0.0001	5.85 ± 0.87	
	25	71.5	1.30	7.5	1.0	380	3.97 ± 0.22	0.0091 ± 0.0002	6.98 ± 0.88	
FBK 1x1 - X5	0	26	0.88	7.5	1.0	380	1.73 ± 0.15	0.0131 ± 0.0006	3.65 ± 0.43	
	0	27	1.88	7.5	1.0	380	2.58 ± 0.13	0.0269 ± 0.0004	7.47 ± 0.45	
	0	28	2.88	7.5	1.0	380	2.80 ± 0.15	0.0413 ± 0.0003	11.83 ± 0.54	
	0	29	3.88	7.5	1.0	380	2.75 ± 0.14	0.0549 ± 0.0003	15.83 ± 0.60	
	25	27	1.33	7.5	1.0	380	1.41 ± 0.13	0.0234 ± 0.0006	7.10 ± 0.52	
	25	28	2.33	7.5	1.0	380	1.71 ± 0.12	0.0407 ± 0.0005	11.94 ± 0.59	
	25	29	3.33	7.5	1.0	380	1.91 ± 0.15	0.0587 ± 0.0006	15.97 ± 0.64	
	25	30	4.33	7.5	1.0	380	2.03 ± 0.17	0.0799 ± 0.0006	14.17 ± 0.55	
	FBK 3x3 - X5	0	27	1.88	7.0	1.0	380	4.31 ± 0.23	0.0189 ± 0.0002	8.30 ± 0.51
		0	27.5	2.38	7.0	1.0	380	4.52 ± 0.26	0.0226 ± 0.0002	8.36 ± 0.48
0		28	2.88	7.0	1.0	380	5.31 ± 0.33	0.0267 ± 0.0002	9.08 ± 0.51	
25		27	1.33	7.0	1.0	380	1.74 ± 0.11	0.0144 ± 0.0002	2.97 ± 0.28	
25		27.5	1.83	7.0	1.0	380	2.11 ± 0.12	0.0181 ± 0.0003	2.82 ± 0.29	
HAM 50u - X5	25	28	2.33	7.0	1.0	380	2.48 ± 0.13	0.0222 ± 0.0003	2.54 ± 0.27	
	0	70	1.10	7.5	1.0	380	3.15 ± 0.15	0.0325 ± 0.0002	6.29 ± 0.38	
	0	70.5	1.60	7.5	1.0	380	4.14 ± 0.21	0.0398 ± 0.0002	7.73 ± 0.42	
	25	70.5	0.30	7.5	1.0	380	2.68 ± 0.15	0.0197 ± 0.0003	4.44 ± 0.36	
	25	71	0.80	7.5	1.0	380	3.41 ± 0.19	0.0299 ± 0.0003	6.06 ± 0.37	
	25	71.5	1.30	7.5	1.0	380	3.94 ± 0.19	0.0378 ± 0.0002	7.28 ± 0.41	